An Approximate Analysis of Handoff Traffic in Mobile Cellular Networks

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Abstract—**Due to scarce radio resources (e.g., wireless link bandwidth), the cell size is likely to become smaller to increase frequency reuse ratio, especially in next generation mobile cellular networks. In this scenario, the analysis of handoff traffic is crucial for adequate QoS provisioning. With the assumption that incoming handoff traffic into a cell is equivalent to outgoing handoff traffic from the cell, we propose an iterative computation technique to analyze handoff traffic approximately. The iterative relaxation method is employed to calculate the steady state probabilities. The call blocking probability and the handoff dropping probability are accordingly obtained. We conduct the approximate analysis of handoff traffic in the case of trunk reservation call admission policy and compare the results with those of simulation experiments.**

I. INTRODUCTION

Over the past decade, the cellular networks have been deployed to provide mobile telephony service to users. The cellular architecture consists of a backbone network with fixed base stations (BSs) interconnected through a fixed network, and of mobile terminals (MTs) that communicate with a BS via wireless links. The geographical area within which an MT can communicate with a particular BS is referred to a cell. A set of channels (time slots, frequencies, spreading codes, or a combination of these) is assigned to each cell and a channel is assigned for communication between an MT and the BS in the cell.

When an MT moves from one cell to another while a call is in progress, the call requires a new channel (in the forward cell) to continue communication. This procedure of changing channels is called handoff. While performing handoff, if no channel is available in the forward cell, the handoff call is dropped. In general, this handoff dropping is more unbearable to users than the new call blocking.

As the cell size becomes smaller, the impact of handoff traffic on quality of service (QoS) in mobile cellular networks is becoming more and more significant. Specifically, three QoS performance measures-the probability of call blocking (P_b), the probability of handoff dropping (P_d), and the probability of forced termination during a call (P_f)-are widely studied in the literature. Among these performance measures, P_f is almost directly proportional to P_d [1], [2]; therefore, we focus on P_b and P_d hereafter. To evaluate the above performance metrics of a cellular system, the handoff traffic should be analyzed, which is the focus of this paper.

The rest of this paper is organized as follows. The analytic model of our cellular system is described in Section II. The iterative analysis technique is discussed in Section III. Numerical results are shown in Section IV. The concluding remarks are given in Section V.

II. MODEL DESCRIPTION

We consider a model in which the MTs move along an arbitrary topology of cells. Each cell has the same capacity of C channels. In each cell, new calls are generated according to a Poisson process with mean rate λ; we assume a spatially homogeneous traffic distribution. The unencumbered call duration time of a call follows an exponential distribution with mean $1/\mu$. Moreover, the cell residence time (CRT) of every MT in a cell is assumed to be exponential with mean $1/\eta$. For the study of generalized distributions of the CRT, please refer to [4] for details.

Our approximate analysis is based on the estimation of handoff call arrival rate, λ_h, into a cell. Also, we adopt the trunk reservation call admission control (CAC) algorithm [1], [3]. In this model, a call is assumed to occupy a single channel. Let t be the number of channels exclusively reserved for handoff calls. In the trunk reservation CAC algorithm, t channels are reserved for only handoff calls to lower the handoff dropping probability. That is, if the number of available channels is less than or equal to t, a newly arriving call is blocked, while a handoff call is always accepted unless there is no more available channel.

If we can know λ_h exactly, the steady probability of state x is calculated by

$$\pi_x = \begin{cases} \frac{1}{G}(\frac{\lambda+\lambda_h}{\mu+\eta})^x / x! & \text{if } x \le C-t \\ \frac{1}{G}\frac{(\lambda+\lambda_h)^{C-t}\lambda_h^{x-C+t}}{(\mu+\eta)^x} / x! & \text{if } x > C-t \end{cases} \quad (1)$$

where state x means that there are x ongoing calls in a given cell. Also, G is the normalization constant and is given by

$$\begin{aligned} G &= \sum_{x=0}^{C-t}(\frac{\lambda+\lambda_h}{\mu+\eta})^x / x! \\ &+ \sum_{x=C-t+1}^{C}\frac{(\lambda+\lambda_h)^{C-t}\lambda_h^{x-C+t}}{(\mu+\eta)^x} / x! \end{aligned} \quad (2)$$

After calculating the steady state probabilities by the above equations, the call blocking probability, P_b, is given by

$$P_b = \sum_{C-t \le x \le C} \pi_x \quad (3)$$

Also, the handoff dropping probability, P_d, is the steady state probability when there is no available channel, and is given by

$$P_d = \sum_{x=C} \pi_x \quad (4)$$

III. The Iterative Analysis

In our approximate analysis of handoff traffic, the basic assumption is a statistical equilibrium between outgoing handoff traffic and incoming handoff traffic when the mobile traffic is assumed to be spatially uniformly distributed over the whole cellular system. That is, from a long-term perspective, the amount of outgoing handoff traffic from a cell is assumed to be equal to the amount of incoming traffic into the cell.

Here, we develop our analytic framework as follows. Let q_{xy} be the transition rate from state x to state y. Then, according to our trunk reservation CAC algorithm, q_{xy} is given by

$$q_{xy} = \begin{cases} \lambda + \lambda_h & \text{if } y = x+1, y+t \le C \\ \lambda_h & \text{if } y = x+1, C-t < y \le C \\ x(\mu+\eta) & \text{if } y = x-1 \\ 0 & \text{otherwise} \end{cases} \quad (5)$$

Also, we define

$$q_{xx} = -\sum_{x \ne y} q_{xy} \quad (6)$$

Let π_x be the steady probability of state x. Also, S is the set of possible states. The steady state probabilities should satisfy the following state balance equations

$$\sum_{x \in S} \pi_x q_{xy} = 0 \quad (7)$$

with the additional normalization requirement that

$$\sum_{x \in S} \pi_x = 1 \quad (8)$$

To calculate the steady probability of state space S, we need to know handoff call arrival rate, λ_h. In the proposed approximate analysis, we estimate λ_h by

$$\lambda_h = \eta \sum_{x \in S} x_i \pi_x \quad (9)$$

Note that the above handoff call arrival rate is approximated by the product of handoff rate (the reciprocal of the CRT) and the average number of ongoing calls. More precisely, (9) represents the outgoing handoff rate from a cell. Recall that our basic assumption is that outgoing handoff traffic is equivalent to incoming handoff rate.

The iterative procedure to calculate λ_h and thereby the steady-state probabilities are described as follows. Initially, λ_h is set to 0. And the corresponding steady-state probability is calculated. (This is so-called the 1st iteration.) Then, we re-calculate λ_h through (5) to (9). There exist quite a few methods for numerical calculation of steady-state probabilities. We employ the iterative relaxation method which boasts of fast convergence [5]. Let $\pi_x^{(j)}$ be the j-th iteration for the steady probability of state x. Let $\sigma(x), x \in S$, be an ordering for x, i.e., a one-to-one mapping from S to $1, 2, ..., |S|$. Given q_{xy}, this method is described by

$$\begin{aligned} \pi_x^{(j)} = \pi_x^{(j-1)} - \frac{\omega}{q_{xx}}(&\sum_{\sigma(y) < \sigma(x)} \pi_y^{(j)} q_{yx} \\ &+ \sum_{\sigma(y) \ge \sigma(x)} \pi_y^{(j-1)} q_{yx}) \end{aligned} \quad (10)$$

where ω, $0 < \omega < 2$, is the relaxation factor. We iterate the above procedure until the convergence is reached.

IV. Numerical Results

In this section, we first explain how to configure the cellular system in the simulation experiments and the performance metrics of the proposed approximate analysis and those of simulation experiments are then shown.

The cellular system assumed in the simulation experiments is depicted in Figure 1. To remove the boundary effect, we design the overall cellular system with the aim that

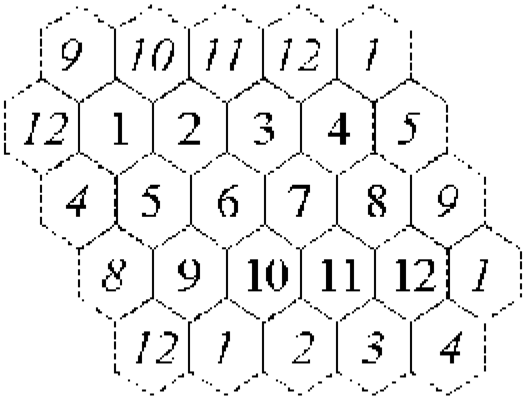

Fig. 1. The Cellular System in Simulation

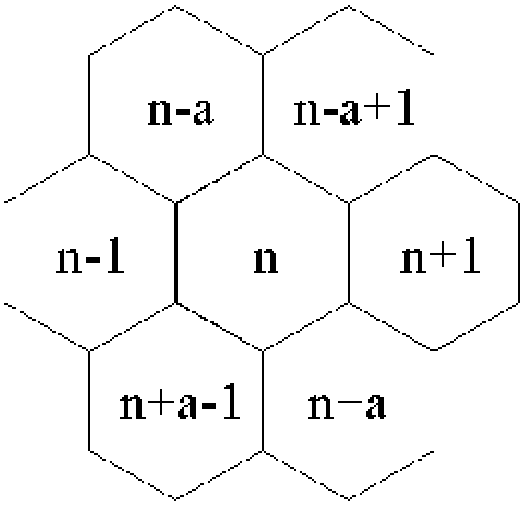

Fig. 2. Cell Index in Handoff

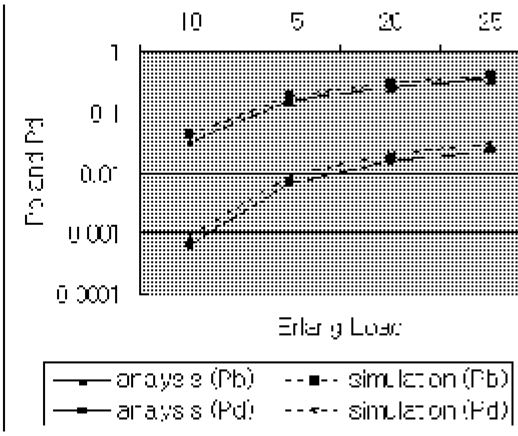

Fig. 3. P_b and P_d when $C = 20$ and $t = 4$

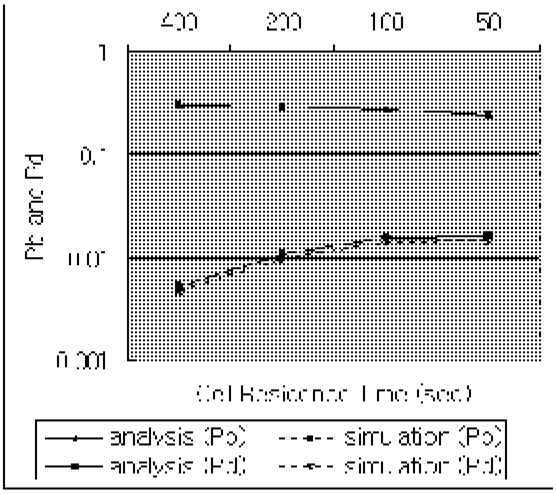

Fig. 4. P_b and P_d when $C = 20$ and $t = 4$

every cell is connected to exactly six neighboring cells. Note that in this figure, the cells in the boundary are fictitiously drawn.

Let a and b denote the number of columns and rows in the cellular system. Then, the total number of cells is $a * b$. From a cell n, an outgoing handoff call from the cell n is assumed to handoff one of six neighboring cells with equal probability $1/6$. The index of six adjacent cells of the cell n is determined by Figure 2. Note that the cell index is calculated by a modular operation of ab. For example, if the calculated cell index $n - a + 1$ is negative, the final index is $n - a + 1 + ab$. Likewise, if the cell index $n + a$ is greater than ab, the final index is $n + a - ab$.

The total available capacity C within a cell is chosen as 20. In Figure 3, the call blocking probability and the handoff dropping probability of our analysis and simulation are shown as the Erlang load increases in the case of $C = 20$ and $t = 4$.

In Figure 4, the call blocking probability and the handoff dropping probability of our analysis and simulation are shown as the CRT decreases (handoff rate increases) where the Erlang load is 20. Note that P_b decreases as the handoff rate increases.

V. CONCLUSION

As the cell size in next generation mobile networks is likely to becomes smaller, the impact of handoff traffic on QoS in mobile cellular networks is crucial accordingly. To evaluate the performance metrics (e.g., the call blocking probability and the handoff dropping probability) of cellular network, the calculation of handoff traffic is a key factor. With the assumption that incoming handoff traffic into a cell is statistically equivalent to outgoing handoff traffic from the cell, we propose an iterative technique to analyze handoff traffic approximately. The relaxation method is employed to iteratively solve the state transition equations. We conduct the approximate analysis of handoff traffic in the case of trunk reservation call admission policy and verify the results by simulation experiments.

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